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## REPORT DOCUMENTATION PAGE

Form Approved  
OMB No. 0704-0188

1a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED		1b. RESTRICTIVE MARKINGS	
2a. SECURITY CLASSIFICATION AUTHORITY DTIC ELECTED		3. DISTRIBUTION/AVAILABILITY OF REPORT Approved for public release; distribution is unlimited.	
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE MAR 03 1988		5. MONITORING ORGANIZATION REPORT NUMBER(S)	
4. PERFORMING ORGANIZATION REPORT NUMBER(S)		7a. NAME OF MONITORING ORGANIZATION Same as 4. above	
6a. NAME OF PERFORMING ORGANIZATION US Army Research Institute of Environmental Medicine		6b. OFFICE SYMBOL (If applicable) SGRD-UE-PH	
6c. ADDRESS (City, State, and ZIP Code) Kansas St. Natick, MA 01760-5007		7b. ADDRESS (City, State, and ZIP Code)	
8a. NAME OF FUNDING/SPONSORING ORGANIZATION		8b. OFFICE SYMBOL (If applicable)	
9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER		10. SOURCE OF FUNDING NUMBERS	
8c. ADDRESS (City, State, and ZIP Code)		PROGRAM ELEMENT NO.	PROJECT NO. 879/BF
		TASK NO.	WORK UNIT ACCESSION NO. 125
11. TITLE (Include Security Classification) Metabolic and Cardiorespiratory Parameters During Three Consecutive Days of Exhaustive Running			
12. PERSONAL AUTHOR(S) Joseph Knapik, James Wright, Michael Welch, Marilyn Sharp, Robert Mello, John Patton			
13a. TYPE OF REPORT Manuscript	13b. TIME COVERED FROM Feb. 82 TO Mar 82	14. DATE OF REPORT (Year, Month, Day) Nov. 87	15. PAGE COUNT 21
16. SUPPLEMENTARY NOTATION			
17. COSATI CODES		18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)	
FIELD	GROUP	SUB-GROUP	
		Glycerol, Respiratory Exchange Ratio, Lactate, Oxygen Uptake, Perceived Exertion	
19. ABSTRACT (Continue on reverse if necessary and identify by block number) Serum metabolites, cardiorespiratory parameters and creatine kinase were examined during running on 3 consecutive days. Thirteen trained marathon runners exercised to exhaustion on a treadmill at 85-93% $\dot{V}O_2$ max on each day. Expired gases and blood samples were obtained at rest, after 10 and 30 min of exercise and at exhaustion. There were no significant differences over days for glucose, insulin, lactate, free fatty acids, creatine kinase, oxygen uptake, minute ventilation, heart rate, rating of perceived exertion, respiratory exchange ratio or run times. Serum glycerol was elevated ( $p < .05$ ) both at rest and during exercise on each successive day. The findings suggested that except for serum glycerol, acute metabolic and cardiorespiratory responses to exhaustive aerobic exercise are not altered by daily repetition at least up to 3 days.			
20. DISTRIBUTION/AVAILABILITY OF ABSTRACT <input type="checkbox"/> UNCLASSIFIED/UNLIMITED <input type="checkbox"/> SAME AS RPT <input type="checkbox"/> DTIC USERS		21. ABSTRACT SECURITY CLASSIFICATION	
22a. NAME OF RESPONSIBLE INDIVIDUAL		22b. TELEPHONE (Include Area Code)	22c. OFFICE SYMBOL

DD Form 1473, JUN 86

Previous editions are obsolete.

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AD-A192 598

**METABOLIC AND CARDIORESPIRATORY PARAMETERS  
DURING THREE CONSECUTIVE DAYS OF  
EXHAUSTIVE RUNNING**

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**KEY WORDS: Glycerol, Respiratory Exchange Ratio,  
Lactate, Oxygen Uptake, Perceived Exertion**

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# ABSTRACT

Serum metabolites, cardiorespiratory parameters and creatine kinase were examined during running on 3 consecutive days. Thirteen trained marathon runners exercised to exhaustion on a treadmill at  $85 \pm 3\%$   $\text{VO}_2$  max on each day. Expired gases and blood samples were obtained at rest, after 10 and 30 min of exercise and at exhaustion. There were no significant differences over days for glucose, insulin, lactate, free fatty acids, creatine kinase, oxygen uptake, minute ventilation, heart rate, rating of perceived exertion, respiratory exchange ratio or run times. Serum glycerol was elevated ( $p < .05$ ) both at rest and during exercise on each successive day. The findings suggested that except for serum glycerol, acute metabolic and cardiorespiratory responses to exhaustive aerobic exercise are not altered by daily repetition at least up to 3 days.



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## INTRODUCTION

Changes in serum metabolites and cardiorespiratory parameters during acute bouts of exercise have been described by many investigators (25); however, there have been few studies that have probed these changes during exhaustive exercise on consecutive days (4). Muscle glycogen has been shown to be progressively reduced by exercise on successive days (4) and as glycogen stores are depleted there appears to be increased reliance on lipids to provide oxidative fuel (19, 24). Oxygen uptake ( $\text{VO}_2$ ) and heart rate (HR) do not appear to be affected (4). The purpose of the present study was to examine alterations in serum metabolites, creatine kinase (CK) and cardiorespiratory parameters during 3 consecutive days of exhaustive exercise.

## METHODS AND MATERIALS

Subjects were 13 male members of a college Marathon Club at the U.S. Military Academy, West Point, NY. Each subject was informed of the purposes of the study and risks involved and gave their written voluntary consent to participate. Their physical characteristics are shown in Table 1. Body fat was estimated from 4 skinfolds using the equations of Durnin and Womersley (6). Lean body mass was estimated from percent body fat and weight.

Maximal oxygen uptake ( $\text{VO}_2 \text{ max}$ ) was determined using a discontinuous, incremental protocol (16). Subjects ran for 4-6 mins. followed by 5-10 min. rest periods. Near the end of each run, expired gases were collected in vinyl Douglas bags and analyzed for oxygen (Applied Electrochemistry<sup>R</sup> Model S-3A) and carbon dioxide (Beckman<sup>R</sup> Model LB-2) concentrations. Gas volume was measured with a tissot spirometer. Heart rate (HR) was recorded electrocardiographically. The respiratory exchange ratio (RER) was calculated as  $\text{VCO}_2/\text{VO}_2$  without correction for urinary nitrogen loss.

Following the  $\text{VO}_2 \text{ max}$  test subjects rested for 24 hours then ran to volitional fatigue (exhaustion) at approximately the same time of day on 3 consecutive days. The treadmill velocity was set at  $12.9 \text{ km}\cdot\text{h}^{-1}$  and the grade was adjusted so that each subject ran at an estimated 85%  $\text{VO}_2 \text{ max}$ . On the first day  $\text{VO}_2$  values were obtained at 5 min. of exercise and final adjustments were made in the treadmill grade to achieve the intended exercise intensity.

Blood samples were collected from a short venous catheter inserted into a superficial arm vein. When samples were not being collected the catheter was kept patent by a 0.9% saline drip provided at a rate of about 1 ml/min. A 10 ml blood sample was collected just prior to exercise with the subject standing on the treadmill. Rating of perceived exertion (RPE, 1), HR and expired gas was collected at minutes 10 and 30 and at exhaustion.

The treadmill was slowed to  $5 \text{ km}\cdot\text{h}^{-1}$  for 2 minutes while a 10 ml blood sample was obtained. Subjects were allowed water ad libitum when exercising.

Blood samples were placed into glass tubes without anticoagulants. Whole blood was used for lactate analysis using an autoanalyzer (Roche<sup>R</sup>). Serum aliquots were used for enzymatic determination of glucose (12), FFA (18), glycerol (23), and CK(Beckman Laboratories Kit). Insulin was quantified using radioimmunoassay (Serrono Laboratories Kit).

Data obtained at rest were analyzed using a one way repeated measures analysis of variance (ANOVA) comparing the 3 days. Data obtained during exercise were analyzed using a two way repeated measures ANOVA comparing the changes during exercise and over the 3 days (2). When significant differences were found the Cicchetti Test (5) was used to isolate these. The 0.05 level of statistical significance was chosen. Values are reported as mean $\pm$ SD.

## RESULTS

The average exercise intensity was  $84.7\pm 2.5\%$   $\text{VO}_2$  max with a range of 81 to 89%  $\text{VO}_2$  max. The average treadmill grade was  $5.2\pm 1.2\%$ . Exercise times to exhaustion did not differ significantly and were  $67\pm 26$ ,  $69\pm 30$  and  $60\pm 30$  min on each consecutive day. Times ranged from 39 to 144 min.

Figures 1 through 4 depict changes in glucose, insulin, lactate and FFA, respectively. Both at rest and during exercise there were no significant differences among the 3 days on any of these parameters. Lactates rose during exercise such that the value at exhaustion was significantly higher than at 10 min.

Changes in serum glycerol are depicted in Figure 5. At rest, glycerol values were significant higher on days 2 and 3 than on day 1 ( $p < .05$ ). During exercise, values were significantly higher on day 3 than on day 1 ( $p < .05$ ).

CK levels are shown in Table 2. There were no significant differences among the 3 days either before exercise or at exhaustion. Cardiorespiratory parameters also showed no significant change over the 3 days as shown in Table 3.

#### DISCUSSION

This study found no changes in the RER and generally no changes in serum metabolites over 3 consecutive days of high intensity, exhaustive treadmill running. An exception was serum glycerol which was elevated on each successive day. Serum glycerol, FFA and the RER have been used as markers of substrate utilization during exercise. Serum glycerols serve as an index of lipid mobilization from adipose tissue (10, 22) while muscle uptake of FFA has been shown to be proportional to their concentration in the plasma (9). There is good agreement between the RER and respiratory quotients calculated from  $a-vO_2$

and  $a\text{-vCO}_2$  differences during steady state exercise (7). The higher glycerol level on day 3 suggested increased lipid mobilization but the unchanging RER and FFA levels over days are not consistent with this interpretation.

A partial explanation for this discrepancy may lie in the elevated lactate values since lactate has been shown to inhibit FFA release (13, 14). A number of mechanisms have been proposed to account for this phenomena. Lactate may have a direct effect on adipose tissue lipase (13). Alternately, hydrogen ions from lactate may combine with NAD leading to the formation of alpha glycerophosphate which in turn produces glycerol. Lipolysis occurs leading to glycerol release but FFA are not released because they are reesterified (13, 14). If the latter mechanism were operational, high lactate levels during intense exercise on successive days may stimulate lipolysis without subsequent FFA release. The RER would not be affected since additional FFA would not be available for oxidation.

Costill et al. (4) had subjects run 16.1 km at 80%  $\text{VO}_2$  max on 3 successive days. Contrary to the findings here, they found evidence for decreasing carbohydrate utilization and increased lipid catabolism since muscle glycogen usage and the RER were reduced and plasma FFA elevated. They also found considerably reduced lactate levels on days 2 and 3. If high lactate levels lead to glycerol production and reesterification of lipids as suggested above, the lower lactate levels in their study may have permitted normal FFA release thus increasing the



availability of lipids for oxidation. In consonance with the results from Costill et al. (4) there were no changes in  $\text{VO}_2$  or HR over the 3 days of exercise in the present study.

CK levels indicated that despite the high exercise intensity and long exercise period there was probably very little muscle damage during the 3 days of exercise. CK levels have been shown to rise for several days after acute, unaccustomed exercise (17, 20) and this has been attributed to skeletal muscle damage (3) or recovery from muscle damage (21). In the present study the CK rise over the 3 days was relatively small (1.2 fold) compared to the 15-33 fold changes that have been reported (8, 20). It is known that regular physical training reduces the rise in CK (8, 11) and subjects in the present study were certainly well trained.

These data suggest that endurance trained individuals can perform exhaustive exercise at high percentages of their maximal capacity for up to 3 days without experiencing alteration in serum substrates, RPE, CK or cardiorespiratory parameters. An exception is serum glycerol which appears to be successively elevated on consecutive days.

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TABLE 1.  
PHYSICAL CHARACTERISTICS OF THE SUBJECTS

	Age (yrs)	Height (cm)	Weight (kg)	Body Fat (%)	Lean Body Mass (kg)	VO <sub>2</sub> Max (ml·kg <sup>-1</sup> ·min <sup>-1</sup> )
Mean	22.2	174.5	69.4	10.5	62.7	65.8
SD	4.6	4.3	7.4	2.1	5.6	3.8

TABLE 2.  
 SERUM CREATINE KINASE (IU·ml<sup>-1</sup>)  
 BEFORE EXERCISE AND AT EXHAUSTION

	DAY 1		DAY 2		DAY 3	
	MEAN	SD	MEAN	SD	MEAN	SD
BEFORE EXERCISE	122	67	149	68	152	93
EXHAUSTION	153	76	184	91	192	121

TABLE 3.  
CARDIORESPIRATORY PARAMETERS AND RPE DURING  
RUNNING ON 3 CONSECUTIVE DAYS

PARAMETER	DAY	10 MIN		30 MIN		EXHAUSTION	
		M	SD	M	SD	M	SD
VO <sub>2</sub> (ml·kg <sup>-1</sup> ·min <sup>-1</sup> )	1	55.6	3.0	54.1	4.9	56.0	2.9
	2	54.0	3.8	54.6	3.6	55.4	2.9
	3	53.8	2.9	54.3	3.0	55.2	2.5
V <sub>E</sub> (l·min <sup>-1</sup> )	1	105.8	17.1	109.0	23.2	121.4	19.8
	2	105.3	21.0	111.6	20.6	123.3	16.1
	3	107.6	17.1	114.6	17.2	126.7	17.3
RER	1	0.94	0.04	0.94	0.04	0.94	0.04
	2	0.93	0.03	0.93	0.03	0.93	0.03
	3	0.93	0.04	0.93	0.04	0.94	0.04
HR (b·min <sup>-1</sup> )	1	170.5	12.8	175.2	12.0	180.8	7.3
	2	167.3	11.3	172.3	11.3	176.5	18.0
	3	166.8	10.9	173.2	11.6	182.0	8.6
RPE	1	12.7	2.4	15.3	2.0	18.5	1.2
	2	11.9	1.8	14.6	2.1	18.5	1.5
	3	12.8	1.6	15.8	2.3	18.7	1.6



#### FIGURE LEGENDS

- Figure 1. Serum glucose changes. Values are means and vertical bars are standard errors.
- Figure 2. Serum insulin changes. Values are means and vertical bars are standard errors.
- Figure 3. Blood lactate changes. Values are means and vertical bars are standard errors.
- Figure 4. Serum free fatty acid changes. Values are means and vertical bars are standard errors.
- Figure 5. Serum glycerol changes. Values are means and vertical bars are standard errors.









